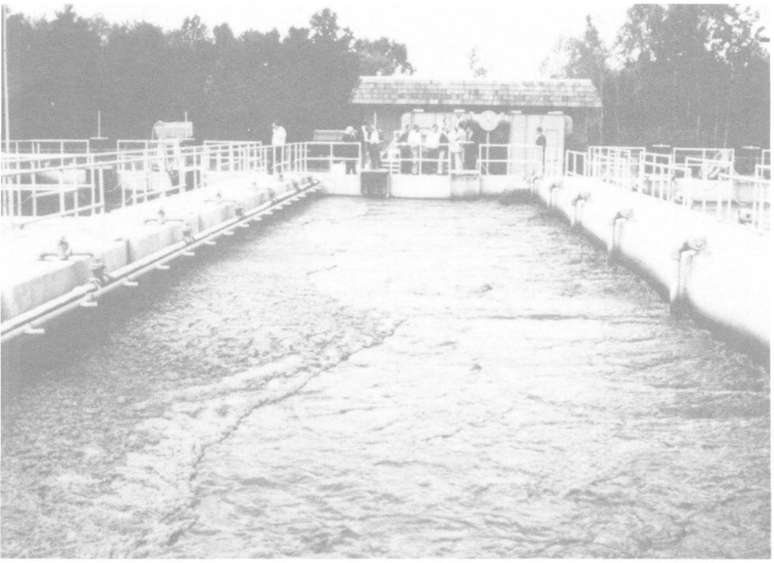
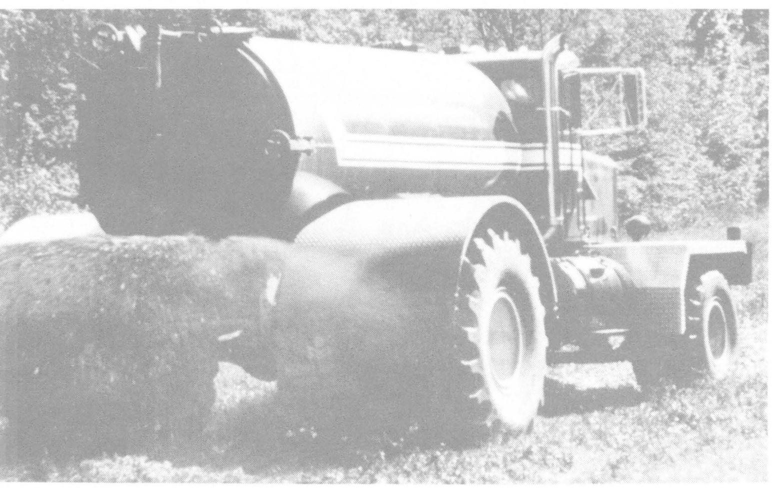
Research Bulletin 1079

Extension Bulletin 598
Agdex 536





Ohio Guide for

Land Application of Sewage Sludge

OSU Cooperative Extension Service
The Ohio State University

Publication Prepared By*

Richard K. White   Albert R. Pugh
Terry J. Logan   Douglas D. Southgate

Ohio Agricultural Research and Development Center
Wooster, Ohio

Ohio Cooperative Extension Service
The Ohio State University
Columbus, Ohio

Revised September 1982

*The following contributed to the current or earlier versions of this publication:

Robert E. Brown, OFBF
Daniel S. Chatfield, ODOH
Daryl R. Clark, OCES
Riley S. Dougan, OCES
D. Lynn Forster, OSU
Gerald C. Grooms, OCES
Faz Haghiri, OARDC
George F. Hall, OSU
Earl Helmreich, ODOH
Robert J. Manson, OEPA
Clifford A. Merritt, OEPA
Robert Miller, OSU
James W. Perry, Hauler
John N. Stitzlein, OCES
Paul R. Thomas, OCES
John F. Trierweiler, OCES
John Vimmerstedt, OARDC
T. Craig Weidensaul, OARDC

This publication was funded in part through a cooperative effort of the U.S. Environmental Protection Agency, the Ohio Farm Bureau Development Corporation, the Ohio Agricultural Research and Development Center and the Ohio Cooperative Extension Service.

For Sale Publication

Issued in furtherance of Cooperative Extension work, Acts of May 8 and June 30, 1914 in cooperation with the U.S. Department of Agriculture, George R. Gist, Acting Director of Cooperative Extension Service, The Ohio State University.

Contents

PREFACE

Sewage sludge has been applied to land for many years in some communities. However, recent regulations and directives of the U.S. Environmental Protection Agency, higher cost fertilizer and concern for efficient energy utilization have generated further interest in land application of sludge.

On one side, municipalities are faced with how best to dispose of sewage sludges produced by the urban and industrial segments of society. Disposal of sludge by incineration and landfill methods now used by most communities is costly and frequently raises serious environmental concerns.

Farmers, though, are concerned about the feasibility of applying sludge to their land. While interested in the economic benefits sludge may have, they are concerned with questions related to application rates, potential hazards of heavy metals, possible odor problems and health hazards that might be associated with sludge application.

Guidelines in this bulletin are based on the most recent research information available and are subject to change as additional research is completed. It must be understood that the information does not indicate what may not be acceptable from a regulatory standpoint. Any regulations governing sludge application will be developed by the U.S. Environmental Protection Agency or Ohio Environmental Protection Agency and local health departments.

The basic intent of this publication is to help farmers make decisions as they consider application of sludge to their land. Further, the information should help municipal officials understand the limitations and capabilities of soil for sewage sludge disposal. The publication also provides information for the public concerning the nature of sewage sludges and their disposal.

Sludge is a resource containing available nutrients. Like the application of any nutrient source, the question to be answered is "What is the most efficient application rate?"

It is not possible to answer that question until at least three factors are known: (1) the composition of sludge being applied; (2) the physical and chemical properties of the soil; and (3) the crop to be grown. With sludge analysis, soil testing and cropping information, application rate recommendations can be made. Later in the publication, detailed instructions are given on computing application rates.

This bulletin provides guidelines for good management practices used in sludge treatment, storage, transportation, and application. These guidelines are keys to a safe and economical sludge landspreading program.

Public Acceptance

Land application of sludge to farmland is a complex and potentially controversial issue. Attention to public acceptance needs to be continual during all phases of the program.

Public acceptance is an important part of any sludge program and success will depend on how involved people are in planning, developing and implementing the program.

Public officials should:

1. Involve from the beginning all those who may be affected by the program.
2. Clearly present all aspects, including benefits and problems.

CHARACTERISTICS OF SLUDGE

The physical and chemical characteristics of sludge depend on the type of sewage and the treatment processes. The specific characteristics can be determined by appropriate testing.

Terminology

Primary sludge is raw sludge obtained in the primary stage of treatment by collecting settled and floating solids. Activated sludge is obtained in the secondary stage of treatment by settling flocculated bacteria cells that have been feeding on the soluble and suspended organic material in the sewage. Primary and activated sludges are further treated to obtain a stabilized sludge in which the organic matter has been decomposed into a relatively stable material. Anaerobic and aerobic digestion are common methods of stabilizing solids which produce a digested sludge.

Sludges may also be stabilized by thermal conditioning (wet oxidation), lime stabilization or composting*. Chemical precipitation, gravity and air flotation processes are used to thicken sludge. Vacuum filters, centrifuges and filter presses are utilized to dewater sludge. Sand drying beds, or dehydrators, may be used to produce a dried sludge.

*Composting of sewage sludges has recently become a viable alternative to other treatment methods. Composting is a thermoplilic, aerobic process. A bulking agent, usually wood chips, is added to the sludge and then the pile is aerated to promote decomposition. After composting for 10-20 days, the material is allowed to cure. Compost is a humus-like material with 50 to 70% solids and is essentially free of pathogens and weed seeds.

Physical Characteristics

The solids content is the main physical characteristic affecting handling and land application methods. If a sludge has five percent solids, it is 95 percent water. Three common ranges of solids content are shown in Table 1.

Table 1: Sludge Solids Content and Handling Characteristics

Type	Solids Content	Handling Methods
Liquid	1-10%	Gravity flow, pump, tank transport
Semi-Solid ("wet" solids)	20-30%	Conveyor, Bucket, truck transport (Water-tight box)
Solid ("dry" solids)	40-80%	Conveyor, auger, loader, truck transport

Sludges with a solid content of 10 to 20 percent are difficult to handle as a liquid or solid.

Chemical Characteristics

Organic matter, fertilizer nutrients, and heavy metals are the chemical components of concern. Tables 2 and 3 present the range of concentration for nutrients and metals in sewage sludge. Sludge composition varies greatly due to variation in wastes entering the treatment plant and types of waste treatment used. Ohio sludges that have been analyzed fall within the ranges given in Tables 2 and 3. Sludges also contain trace elements other than those listed, and may contain toxic organics such as PCB's.

Sludge Testing

Types of Analyses

Sewage sludge analyses should be made for a minimum of three months preceding land application. Each monthly sample should be a composite of daily samples. These analyses provide a reasonable evaluation of expected sludge quality and variability. Monthly analyses should be continued thereafter to assure acceptable sludge quality for land application. Any farmer receiving sludge should be provided representative sludge analyses before sludge application, which includes the following:

pH

Percent solids

Nutrients - ammonia (NH_4-N), total kjeldahl nitrogen (TKN), total phosphorus, total potassium.

Metals - copper (Cu), cadmium (Cd), zinc (Zn), nickel (Ni), lead (Pb)

Analyses for other inorganic or organic constituents may be necessary if unusually large industrial inputs into the sewage flow are suspected. All results of nutrient and metal sludge concentrations should be expressed as ppm, ug per g, or mg per kg on a dry sludge basis.

Nutrients in sludge must be known so the grower can determine whether supplemental chemical fertilizer is needed to balance crop requirements. Sludge application rates are often made to provide the total nitrogen or phosphorus requirements of the crop (See "Crop Management" section). Accurate sludge analysis for these nutrients is needed.

The metals listed affect crop production and food chain contamination. Accurate sludge analysis is needed to limit the amounts of these metals added to land with the sludge. Types and quantities of metals in sludge vary considerably from one municipality to another. Metals would be expected in greatest amounts in sludge from municipalities that have heavy machine industries, battery manufacturing plants or plating industries. Metals are usually less significant in sludge from primarily residential areas. However, determination of metal content should be made regardless of the sludge source. Where other

Table 2: Range and Median of N, P and K Contents of Digested Sewage Sludge

	Range	Median*	
Component	%	%	lbs/ton
Total Nitrogen	1.5-4.5	3.3	66
·Organic Nitrogen	1.5-3.0	2.0	40
P (Phosphorus)	0.5-4.0	2.5	50
P_2O_5 (Phosphate)	1.1-9.2	5.7	114
K (Potassium)	0.1-2.0	0.3	6
K_2O (Potash)	0.12-2.40	0.4	7

*The median is that value for which 50% of the observations, when arranged in the order of magnitude, lie on each side.

Table 3. Trace Element Concentrations in Digested Sewage Sludge

Element	Range mg/kg*	Median mg/kg*	Median lbs./ton
Boron	10-800	50	0.1
Cadmium	3-3000	15	0.03
Chromium	20-30,000	1000	2.0
Cobalt	2-20	10	0.02
Copper	85-11,000	1000	2.0
Nickel	10-4000	100	0.2
Manganese	60-7000	300	0.6
Mercury	0.5-10,000	5	0.01
Molybdenum	20-30	30	0.06
Lead	50-20,000	500	1.0
Zinc	100-28,000	2000	4.0

*Equivalent to parts per million on a dry weight basis. To convert ppm to pounds per ton, multiply by 0.002.
Ref.: Unpublished data, North Central Regional Committee 118 report entitled "Utilization and Disposal of Municipal, Industrial, and Agricultural Processing Wastes."

metals and toxic compounds are known to be present in high concentrations in sludge, they also should be tested routinely.

Many of the larger treatment plants provide their own sludge analysis while others may employ private or state laboratories for testing.

Collecting A Representative Sample

Daily "grab" samples of a liquid sludge (approximately 1/2 pint) should be transferred to a two-gallon water tight covered container left in a refrigerator. After one month, the large composite sample should be mixed thoroughly and a quart sub-sample removed for analysis. Again, use a plastic, water tight, covered container. Deliver the quart sample or ship it to the analytical laboratory as rapidly as possible in a well insulated shipping container. During very warm seasons, pack the sub-sample with dry ice to prevent microbial activity during shipping. Alternatively, acid can be added to decrease the sludge pH to about 1.0 prior to shipping.

Handle sludge samples from vacuum filters, centrifuges or lagoons similarly to liquid sludges. A sludge sample from a drying bed should be a composite of 6 to 12 individual sub-samples. Dried sludge can be placed in strong plastic bags rather than plastic containers and shipped without dry ice, unless shipping times are usually long.

"Nuisance" Considerations

Most anaerobic, aerobic, composted or lime stabilized sewage sludges do not have an offensive odor. Sludges that do have an odor are usually associated with mechanical failure of the digester, poor treatment plant management or sludge removed during periodic cleaning of the digester.

The odor nuisance from these sludges can be minimized by various management decisions at the time of land application. Spread odorous sludges away from residences and at lower rates than normal. Rapid incorporation is recommended on tilled soils. Direct injection of sludge below the soil surface is also an effective way of handling odorous sludges.

If sludge storage lagoons are located in the area of application, they should be located a minimum of 1500 feet from any residence.

SITE SELECTION AND MANAGEMENT

The primary reason for applying sewage sludge on agricultural land is to utilize the nutrients in sludge for crop production.

Consideration must be given the crop to be grown and its nutrient requirements, along with those soil and landscape characteristics that determine the ability of agricultural land to receive sludge in an environmentally safe manner.

Crop utilization of sludge nutrients with minimal environmental risk can be achieved if: (1) rates of sludge application are tailored to the nutrient requirements of the crop and the physical features of the site and (2) metals added to soil in sludge do not exceed the guidelines discussed later (See "Excess Heavy Metals" section). In most cases, annual rates of sludge application will be less than five dry tons per acre. At these rates, environmental risk is minimal. The soil's ability to safely handle sludge decreases as the application rate increases above the five dry tons per acre rate. Higher rates can be applied on some soils if managed and monitored closely.

Soil and landscape characteristics that must be considered for sound management of land application of sludge are discussed in next section. County soil survey reports prepared by the Soil Conservation Services (SCS) and the Division of Lands and Soils, Ohio Department of Natural Resources and farm plans prepared by SCS and Soil and Water Conservation District (SWCD) personnel for individual farms contain much of the pertinent soil and landscape data discussed in the next section. The county soil survey reports have been completed for much of Ohio and are available from SCS, SWCD and County Extension Service offices.

Landscape Features

Slope

Sludge should not be spread on slopes greater than 12 percent. On 6 to 12 percent slopes, spread sludge only when: (1) at least 80 percent of the soil is covered with vegetation, (2) immediate incorporation or injection is possible or (3) erosion control practices meet recommendations in the "Ohio Erosion Control and Sediment Pollution Abatement Guide," Ohio Cooperative Extension Service Bulletin 594.

Proximity to Water, Roads and Dwellings

Required isolation distances from water bodies, residences and roadways will vary with application rates and methods of sludge incorporation. As a general rule, the isolation distances should be maintained (Table 4):

Flood Hazard

Do not apply sludge to soils subjected to more than a 10 percent chance of flooding per year.

Shallow Soils

Sludge application rates of five dry tons per acre or less are recommended for soils less than five feet thick overlying fractured bedrock, permeable sands or gravels. Relatively low application rates are recommended because of the potential leaching of soluble sludge components (primarily nitrate-nitrogen) into groundwater.

Table 4. Isolation Distances (Feet) for Land Application of Sludge

Site Controlling Factor	Liquid Sludge Surface Application at rate of tons/acre/year <2	2-5	>5	Liquid Sludge Injection or Immediate Incorporation at rate of tons/acre/year <2	2-5	>5	Dried Sludge (30% Solids) tons/acre/year <2	2-5	>5
Neighbor occupied building	300	300	300	100	100	100	100	100	100
Public road right-of-way	0	0	0	0	0	0	0	0	0
Wells	50	50	50	50	50	50	50	50	50
Ponds, lakes, ditches, streams or grassed waterway	25	100	300	25	50	100	25	25	25
Ponds, lakes, ditches, streams with level ground (less than a 6% grade) and protected by berm or vegetated barrier or dead furrow (distance from barrier)	0	0	0	0	0	0	0	0	0

Application of sludge in excess of two dry tons per acre is not recommended when a perched water table is within a foot of the surface. On very poorly drained soils, restrict sludge application rates unless adequate surface or tile drainage is provided.

Seepage

Avoid high rates of sludge application on land with pronounced lateral seepage.

Soil Properties

Chemical Properties and Soil Testing

Make standard soil tests prior to sludge application so growers can determine the nutrients that will be available from the soil. Composited soil samples for this test should represent no more than 20 acres. These tests consist of pH, cation exchange capacity, lime test index, available phosphorus, exchangeable potassium, calcium and magnesium.

Soil pH and cation exchange capacity (CEC) are used to determine safe levels of heavy metals that can be added in sludge (See "Excess Metals" section). Standard soil tests are run by the Research and Extension Analytical Laboratory (REAL) at the Ohio Agricultural Research and Development Center at Wooster, Ohio, and by a number of private laboratories within the state. A bulletin on proper soil sampling technique is available from County Extension Service offices.

Some recommendations concerning the tests are as follows:

pH: The pH of the plow layer (0-8 inches) should be 6.5 or greater. Plants will accumulate more heavy metals from a soil with a pH less than 6.5.

Cation Exchange Capacity (CEC): Soils with higher cation exchange capacities have greater ability to hold and immobilize heavy metals. Table 6 in the "Excess Heavy Metals" section relates sludge loading rates to CEC. Cation exchange capacities of Ohio soils are given in milliequivalents per 100 grams of soil (meq. per 100 g soil). CEC is best provided from standard soil tests, but in the absence of test data, CEC can be estimated from soil texture (Table 5).

Table 5: Range of Cation Exchange Capacities for Ohio Soils

Soil Textural Groups	CEC meq/100 g soil
Coarse	5-10
Medium	10-20
Fine	20-50
Organic Soil	greater than 50

Background Heavy Metals: In areas that may have received previous applications of sewage sludge or other wastes, it is important to determine the total metal content of the soil for the five metals listed in Table 6.

Table 6. Concentration of Metals in Uncontaminated Ohio Soils

	mg/kg
Zinc	75
Copper	19
Nickel	18
Cadmium	0.2
Lead	19

Table 7: The Maximum Amounts of Heavy Metals That Can Be Applied to Land Safely* (pounds per acre)

	Soil Cation Exchange Capacity (meq/100 g soil)		
Metal	0-5	5-15	more than 15
Cadmium	5	10	20
Copper	125	250	500
Nickel	125	250	500
Zinc	250	500	1000
Lead	500	1000	2000

*These values assume a soil pH of 6.5 or greater.

The difference between the test value and the uncontaminated level in mg/kg (Table 6) is multiplied by two to convert it to pounds/acre. This value represents that amount of the metal that has already accumulated in the soil and must be subtracted from the value in Table 7 to determine the remaining capacity of the soil to safely accumulate the metal.

Organic Matter: The ability of mineral soils to inactivate the heavy metals in sludge increases as organic matter content increases. Organic matter increases CEC and also immobilizes some of the metals.

Phosphorus Retention: Sludges contain a large amount of phosphorus, all of which will become available with time. At low sludge application rates, the phosphate is used by the crop and buildup in the soil is not a problem. At rates in excess of two dry tons per acre per year, available phosphate levels will increase rapidly in soils with a low phosphate retention capacity (sandy and organic soils).

Physical Properties

Texture: Texture is probably the most important physical characteristic of soils. It affects many of the other soil physical and chemical properties. In general, the limitations on sludge application by texture include:

Sands, loamy sands: Leaching of nitrates and other soluble sludge components is the major hazard. This should not be a problem if sludge application rates do not exceed the nitrogen requirement of the crop. Sands also have low phosphate retention capacity, low CEC and low buffer capacity (do not resist changes in pH).

Loams, sandy loams: These soils have few limitations to sludge application.

Silt loams: Major limitations include soil crusting, erodibility, and potential for compaction.

Clays, silty clays, clay loams, silty clay loams: Major limitations are poor drainage, poor aeration, slow permeability and potentially serious problems with compaction. These limitations are less restrictive at sludge application rates less than five dry tons per acre and when applications are not made on wet soils.

Structure: Soils with tight subsurface structure restrict water movement, resulting in impaired drainage and poor aeration. Application of high rates of sewage sludge on soils with such subsurface horizons (for example,fragipans) should be avoided.

Soil Erodibility: The susceptibility of a soil to erosion depends on many factors. The most important are slope, soil texture and vegetative cover. The greatest hazard is on fine textured soils. Avoid sludge application on sloping, fine-textured soils unless vegetative cover is maintained to increase infiltration. Unincorporated sludge on bare slopes greater than 6 percent will move during runoff. Erosion control practices should meet the recommendations in the "Ohio Erosion Control and Sediment Pollution Abatement Guide," Ohio Cooperative Extension Service Bulletin 594.

Soil Permeability: Liquid sewage sludges normally contain between 92 and 98 percent water. Avoid soils with either very high or very low permeability. Highly permeable soils are susceptible to leaching, and soluable sludge constituents (primarily nitrate-nitrogen) may contaminate the groundwater. Those with low permeability have internal drainage problems that restrict sludge decomposition. These problems, however, are minimal at sludge application rates less than two dry tons per acre per year.

Drainage: Successful decomposition of sludge organic matter in soil requires good aeration. Avoid sludge application rates greater than 2 dry tons per acre on soils with poor internal drainage. Poorly drained soils should have subsurface drainage whenever possible.

Soil Compaction: Crop-yield reduction may result from soil compaction restricting plant root development. A dry soil can sustain higher unit tire loads than wet soils without causing a compaction problem. The use of high flotation tires (terra-tires) will decrease soil compaction but still may cause problems in wet, clay soils. The total land application system needs to be designed and managed to avoid serious compaction.

TRANSPORTATION AND APPLICATION

Proper transportation and application techniques are determined by the physical characteristics of the sludge. Will it be handled as a liquid, semi-solid or solid? It is assumed that the sludge to be applied to land is digested or stabilized. In the digestion process, the total solids content normally ranges from three to five percent, i.e., 97 to 95 percent water. The solids content can be increased by various processes at the treatment plant, such as thickening, dewatering or drying. Composted sludge normally will have a solids content of 50 to 70 percent. The decision about the solids content of the sludge will dictate the equipment for transporting the sludge, and applying it to or incorporating it into the soil.

Other factors affecting the method of transport and application are: (1) quantity of sludge produced (size of the city), (2) distance to spreading site, (3) spreading site characteristics (topography, vegetative cover, soil type, acreage available), (4) storage capability and (5) time of application (weather, soil conditions and cropping pattern).

Environmental concerns affecting the method of applying sludge to cropland are: control of surface and groundwater contamination, odor and aerosol (mist) control. Environmental problems can be minimized by proper management, e.g., utilizing some storage, selection of equipment or providing alternative sites for use during adverse weather.

The two most common methods of applying sludge are: (1) in the "liquid" form using a tank truck or (2) in the "cake" form using a spreader truck. Both methods will use a "nurse" truck if the haul distance to the application site becomes great, e.g., five or more miles. Some cities are utilizing irrigation equipment for slurry application.

Small municipalities most likely will use tank trucks that allow flexibility in selecting application sites and time of application. Medium flotation tires will allow over-the-road hauling and field spreading under most conditions. However some storage capacity is needed in the total system to avoid times when fields are inaccessible due to weather or crops. If a nurse truck is used for over-the-road hauling, then the spreader truck will usually have high flotation tires. The high flotation tires will give greater flexibility in timing of application and cause less compaction.

Large cities are likely to consider applying sludge cake because of longer haul distances and large quantities of sludge. The total costs--capital and operating--for dewatering sludge are high. Only larger cities can obtain the economies of scale to justify its use.

An important design and management consideration is to prevent spillage of sludge when hauling to the application site. Truck routes should avoid residential streets. Hauling should not be done at night. Provisions need to be made to remove soil, mud, etc., from spreading equipment that may be "tracked-out" onto roads from fields.

Figure 1. Tank truck with gravity discharge.

Tank Trucks

Commercial tank truck spreaders are available. Those with high flotation tires for traversing soft ground will have a restricted road hauling range. Trucks with regular tires can be used on grass covered, dry fields. Attachments for tank trucks to allow field spreading are very simple. They involve a quick opening-closing valve and deflector plate to fan the slurry over a wider area. In most cases, gravity discharge is used, but some commercial tanks can be pressurized or pumped. Figure 1 shows a tank truck with gravity discharge and high flotation tires. Consider a pressurized tank or pump discharge if only one unit is to be used and regular field application is required.

Truck Spreaders

The process of dewatering sludge permits hauling less water to fields. When five percent sludge is dewatered to 25 percent, approximately 85 percent of the water is removed.

Commercial fertilizer spreader trucks have been adapted to give capabililty for spreading sludge cake. In some cases a "new breed" of truck spreaders has been developed. Figure 2 shows a hopper bottom truck with hydraulic spinners on the back spreading sludge on land.

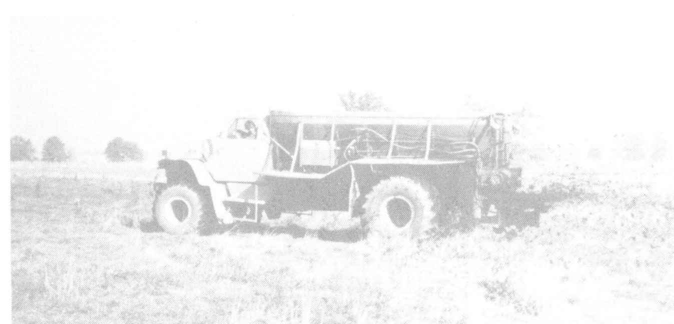


Figure 2 Hopper bottom truck with hydraulic spinners on the back.

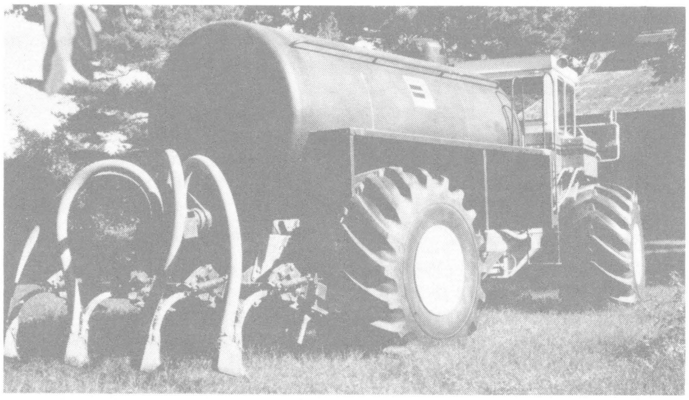


Figure 3. Tank truck with injection equipment.

Immediate Soil Incorporation

In situations requiring nuisance odor control, immediate incorporation of sludge into the soil is desirable. This can be done with several types of commercial equipment: chisel injector on tank truck, flexible hose attachment to moldboard or disc plow, or surface spreading followed by plowing and/or discing. Figure 3 shows a tank truck with injection equipment. Incorporation will also reduce the potential for pollution runoff and volatilization of ammonia-nitrogen in sludge.

Irrigation

Where limited storage requires regular access to fields, the irrigation option is available. Experience indicates that a transfer-storage tank at the field site is essential. The haul truck discharges its loads into the tank. Then the sludge is pumped from the storage tank through the irrigation equipment. A self-propelled irrigation system, shown in Figure 4, will give flexibility and control of the application rates. A system with portable pipes and a hand-moved nozzle can be used by small municipalities. An aerosol drift problem may occur so that isolation and location with respect to wind direction is important.

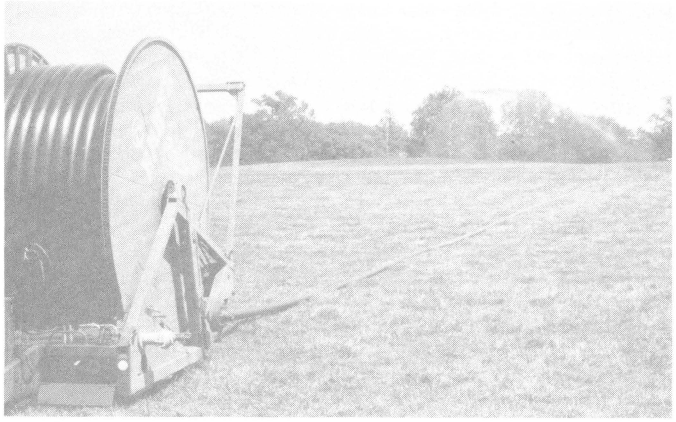


Figure 4. Traveling gun flexible hose system.

CROPS CONSIDERATIONS

Crop Selection

Corn, soybeans and wheat are the major grain crops grown in Ohio. Sludge can be used effectively on all of these as a supplemental source of nitrogen and phosphorus. These crops have an advantage--less metals accumulate in grain than in leaves. Annual and perennial forage legumes and grasses can also benefit from the nutrients in sludge. However, sludge should not be used on forages consumed by lactating dairy cattle (see "Health Concerns" section). Additional safeguards for animal health are achieved by applying sludge to forages only after pastures are grazed down or cut and before appreciable regrowth.

Some sludge may be applied to forest soil as well. Then, however, nitrification can be an environmental concern. If nitrification occurs, nitrate leaching to groundwater or surface water supplies is a major environmental hazard; however many forest sites have soil pH levels less than 5, which may limit nitrification. Undisturbed forest soils contain large pores that transport water rapidly--vertically and laterally. These pores, earthworm and insect tunnels, small mammal burrows and old root channels, may extend downward for several feet and laterally for tens of feet. In sandy soils, root channels fill up with sand. In finer textured soil, the channels persist like drain tile. Clay skins and root bark prevent water movement from the pores into adjacent soil. Problems associated with vertical and lateral flow will be particularly serious where fractured bedrock or permeable sand or gravels are close to the surface. Pollution of streams by lateral flow could be interrupted by thoroughly disturbing a strip of soil between the sludge application area and the watercourse.

Application of large amounts of liquid sewage sludge on forest sites with steep slopes (greater than 6%), which lead into streams or open drainage systems, presents the potential for surface water pollution because of downslope flow of the sludge. Accumulated litter may be beneficial in retaining the sludge against excessive downslope flow and alleviate the problem. Yet, excessive slopes on forested sites must be treated with a great deal of caution because sludge incorporation is usually impossible.

Heat dried, heat processed, lime treated or composted sewage sludges can be used as organic amendments and supplemental nutrient sources for turf farms, lawn establishment or for ornamental plants. Heavy metal and nitrogen limitations also apply to these plants, and it should be noted that some ornamentals may be more sensitive to heavy metal toxicity than agronomic crops.

Crop Management

Sludge contains plant nutrients (See "Characteristics of Sludge" section). When used by the farmer with proper management, it is a valuable supplement to chemical fertilizer. The primary nutrients supplied by sludge are nitrogen and phosphorus. Application rates may be designed to provide all or part of the crop requirements for these nutrients. Only four to five dry tons per acre of sludge is generally needed to supply the nitrogen required by a crop like corn. When sludge rates are kept below the crop nitrogen requirements, the potential for nitrate leaching is almost eliminated.

Sludge also contains varying amounts of metals, which can be toxic in the food chain when concentration is high. Therefore, the quantity of sludge that can be applied safely on soil must take into account the amount of heavy metals applied as well as the nutrient requirements of the crop. When the heavy metal content is high, the sludge application rate will be determined by the amounts of these metals that can be tolerated safely. Some sludges may be so high in metals that they cannot be safely used on agricultural land.

Nutrient Requirements

On the average, a ton of dry sludge contains about approximately 65, 50 and 5 pounds of nitrogen, phosphorus and potassium, respectively. All of the phosphorus and potassium is considered available to the plant. Some of the nitrogen in sludge is ammonia (some sludges may also contain small amounts of nitrate) and the rest is organic nitrogen. Sludge analysis will give the exact amount of each nutrient present. Nutrients will vary dependent upon sludge source and treatment.

All of the ammonia (and nitrate) is immediately available to the plant. About 30 percent of the organic nitrogen is estimated to be available in the year of application. About five percent of the residual organic nitrogen will be available annually to the crop in subsequent years.

In order to determine sludge application rates and supplemental fertilizer needs, the following information is needed: (1) Sludge analysis--total Kjeldahl N, ammonia N, total phosphorus, total potassium and percent solids. (2) Soil test--available phosphorus and exchangeable potassium. (3) Crop data--previous crop(s), crop to be grown and yield goal.

The above are needed to determine N, P and K requirements using the Agronomy Guide, Ohio Cooperative Extension Service Bulletin 472. A sample calculation is given in the appendix for determining sludge application rates.

When sludge is not immediately incorporated, some of the ammonia may be lost to the air by volatilization, thereby reducing the nitrogen supplied by the sludge. Additional ammonia loss varies with soil moisture content, temperature and pH. Accurate estimates of total ammonia loss are not known but appear to be in the range of 5 to 40 percent.

Because sludge is not a balanced fertilizer, application over time may result in an imbalance of nutrients. This should be checked with regular soil and plant analysis; then supplemental fertilizer can be added to balance crop requirements.

Excess Heavy Metals

Sewage sludge contains elements essential for the growth of higher plants. However, it also contains other elements that might be harmful to crops and to the food chain if applied to soils in excessive amounts. These elements are: zinc (Zn), copper (Cu), nickel (Ni), cadmium (Cd), chromium (Cr), mercury (Hg), lead (Pb), boron (B), molybdenum (Mo), cobalt (Co) and selenium (Se).

The trace elements zinc, copper and nickel are toxic to plants when they occur in soil in significant amounts. Cadmium in high concentration in soil is toxic to plants. Normally, cadmium content of most sludges are not high enough to cause plant injury. Chromium present in sludge applied to soil is converted to a form that is not taken up by or harmful to plants. Lead can be toxic to plants in acid soils that are also low in phosphate. However, lead in sludge appears to be non-toxic because the large amount of phosphate in sludge ties up the lead and prevents injury to plants. Boron at the levels present in sludge is not harmful to plants, except perhaps in soils normally high in boron. The concentrations of molybdenum, selenium and cobalt in domestic sludges are low and unrealistically high rates of sludge would be required for soils to attain toxic levels of these metals.

Metals found in sewage sludge, with the exception of cadmium, copper and zinc constitute no hazard to the food chain through plant accumulation. However, surface contamination of vegetation by recently applied sludge containing these metals could be a special hazard to grazing animals. To prevent surface contamination of pasture or forage crops, it is recommended that pastures be grazed and cut, or hay cut and removed prior to sludge application. The grass or legume will grow back without contamination of leaf surfaces with the sludge.

Excess zinc: If an animal's diet contains between 500 and 1,000 ppm (parts per million) zinc, it is toxic. Plant yields however are reduced at zinc concentrations in the plant of less than 500 ppm and, the food chain should not be jeopardized.

Plants exposed to excessive levels of copper will be injured before they can accumulate enough copper to be toxic to most animals. However, sheep are very sensitive to copper. Toxicity results when sheep diets contain 12 to 15 ppm copper.

The potential hazard of cadmium to human and animal health is a major concern because cadmium will accumulate in plants to levels high enough to contaminate the food chain but not high enough to reduce crop yields. Zinc inhibits the uptake of cadmium from soil by crops and decreases accumulation of cadmium in animal tissue. The lower the ratio of cadmium to zinc in sludge, the lower the potential toxic effects of cadmium on the food chain.

Factors affecting the accumulation of sludge-born heavy metals by crops are: pH, cation exchange capacity, organic matter, phosphorus and crop species. In general, the availability of heavy metals in the soil decreases as the pH approaches seven. There is little uptake of heavy metals by plants when soil pH is greater than 6.5. Soils with a higher cation exchange capacity can retain more heavy metals. This, in turn, reduces the amount of heavy metals available to plants. Soil organic matter plays an important role in retaining heavy metals through its high cation exchange capacity and chelating ability. Phosphates reduce the stunting injury to plants from high levels of copper, zinc, and nickel and also precipitates lead in the sludge.

Plant species and varieties vary in their abilities to accumulate heavy metals. Based on current knowledge of relative crop tolerances to heavy metals, vegetable crops such as beets, kale, mustard, turnips and tomatoes are very sensitive. Field crops such as corn, soybeans and small grains are moderately tolerant and most grasses (e.g., fescue, bermudagrass and perennial ryegrass) are classified as tolerant. The concentration of heavy metals in the vegetative tissues of plants are much higher than in fruits and seeds.

Various guidelines have been proposed for limiting sludge to soil on the basis of the heavy metal content of the sludge. One approach, which is presently considered the most useful guide, bases application rates of five important heavy metals on the maximum amounts that can be applied to soil (Table 7). The maximum amount of sludge that can be applied to land will be reached when the allowable level of any one metal is exceeded. The allowable metal additions are higher for soils with greater cation exchange capacities (CEC). These metal additions apply only to soils that have a pH of 6.5 or greater when sludge is applied. Soils should be managed to keep the pH at or above 6.5. In addition, it is recommended that the annual rate of cadmium addition should not exceed two pounds per acre.

Time of Application

Sewage flow and sewage treatment are continuous. This means sludge is produced on a daily basis. Well-planned and managed land application systems for sludge must take this into account.

Sewage treatment facilities contemplating land application should consider providing at a minimum one month's sludge storage or alternate sludge handling option. This will provide a place for sludge during those periods when agricultural land is unavailable or severely limited in availability. Treatment plants, during construction or expansion, should provide sludge storage as part of plant design. Alternatively, municipal owned land in proximity to the plant often can be managed to provide environmentally safe alternatives to farmer owned land for short time periods during the year.

When to apply sludge to agricultural land depends upon the crop being raised and the soils of the region. Sludge used as the only source of phosphorus can be applied almost any time during the year when it does not interfere with farming operations. For crops such as corn, soybeans and wheat, sludge can be applied before planting and after harvesting but not during the growing season. Forage and pastures provide an opportunity for spreading throughout the year after grazing down or mowing. Sludge can also be applied at relatively low rates (less than 5 tons per acre) on snow covered, frozen soils with moderate slope or adequate plant cover to reduce runoff. Runoff of sludge can be reduced by suspending or restricting sludge application during the late winter or early spring when snow melt and water runoff is most likely.

Periods of excessive rainfall also limit sludge application by limiting access to tilled fields and increasing the chance of soil compaction on both tilled fields and pastures and hay land. Application vehicles with flotation tires will be essential on many soils in Ohio to facilitate sludge application with a minimum of compaction. Even with flotation equipment, there may be days when wet fields will not allow sludge application due to rutting.

Sludge application to forest land presents a special concern. Trees are perennial crops and must survive cold winters in many areas of the country. Application of sewage sludge in late summer or early fall could prevent development of cold hardiness by stimulating a new flush of rapid twig growth. Therefore sludge should not be applied to forest land in late summer or early fall. The optimum time for application will be in spring and early summer, until mid-July.

HEALTH CONCERNS

Low numbers of pathogenic bacteria and viruses as well as some intestinal parasites may survive the sewage treatment processes and be present in sewage sludges. Lime treated, heat treated, composted or old lagooned sludges should be essentially pathogen and parasite free.

The presence of pathogenic organisms and parasites does not limit land application as long as some reasonable precautions and good management practices are followed. Exposure to sunlight, drying and the rapid mortality of pathogens and parasites in soil after the sludge is incorporated provide additional safeguards when sludge is applied to land.

Individuals handling sludge should practice normal personal hygiene. If mists are generated during application of liquid sewage sludges, workers should consider the use of face masks.

Lactating dairy animals should not be grazed for one year on pastures which have received sludge. This recommendation recognizes two potential risks to lactating dairy cattle being pastured on or consuming hay from fields that have received sludge. First, sludges may contain the eggs of intestinal worms which could be transferred into milk by udder contamination. Second, chlorinated or brominated chemicals, e.g., pesticides or PCB's and PBB's, may be present in high concentration in some sludges. Although these chemicals are not absorbed from soil by plants, direct application of sludge to forage or pasture vegetation could result in their ingestation by dairy cows. These chemicals could move into the butterfat and adversely affect milk quality and marketability.

The presence of low numbers of intestinal worm eggs and pathogens in sludge also restricts the use of sludge on vegetable and root crops. It is recommended that vegetables and root crops, which are eaten raw, not be grown on soils that have received sludge until one year after application. Use of crops such as green beans, sweet corn, potatoes, etc., which may contaminate other foods in the kitchen before cooking, should be restricted in the same manner.

Cadmium is also a health concern because of the possible relationship of cadmium in the diet and certain human health problems. Proper management of land application of sludges can effectively control the accumulation of cadmium in food crops and protect both human and animal health. These management steps have been discussed in the "Crop Management" section.

The public has recently questioned the possibility of synthetic organic compounds from industry accumulating in sludge and affecting animal and human health where sludge is used on agricultural land. Biodegradeable organic compounds will degrade during the treatment processes. Resistant organics such as chlorinated hydrocarbons, some halogenated insecticides, PCB's and PBB's are almost always present in very low concentrations in sludge. These compounds are not absorbed from soil by higher plants but may be ingested by animals grazing on pasture recently receiving sludge.

ECONOMIC CONSIDERATIONS

Substituting Sludge for Commercial Fertilizer

Sludge has a wide array of potentially valuable properties. It supplies nutrients, organic material and trace elements and improves soil structure. However, the relatively low application rates recommended in this Bulletin for environmental reasons will limit benefits of increased humus content or improved soil structure. Also, trace elements are not of primary concern on most Ohio soils. Therefore, THE PRIMARY BENEFIT OF SLUDGE IS ITS PRIMARY NUTRIENT (NPK) VALUE.

The nutrient value of sludge equals the value of commercial fertilizer being replaced. Generally, if between one and two dry tons of sludge are applied per acre, all of a crop's phosphorus needs will be met as will part of its nitrogen and potassium needs. (Thus, sludge application is usually accompanied by application of nitrogen and perhaps potassium.) Table 8 indicates the potential value of sludge when all nutrients are utilized by a crop.

The precise value of sludge on a particular farm depends on the crop to be grown, the yield level desired, the soil characteristics, the nutrient content of the sludge, the application rate and the price of nutrients from other sources.

The procedure to use in computing this value is: (1) determine the nutrient needs of the crop to be grown; (2) compute the quantities of nutrients being supplied by sludge by multiplying the sludge's nutrient content by the application rate; and (3) place value on these nutrients.

The last step involves more than a simple multiplication of sludge nitrogen, phosphorus and potassium contents by their respective prices. For example, if sludge is applied to meet the nitrogen needs of corn, it is probable that phosphorus is applied at twice the rate that is needed by that year's crop. In this case, it would be inaccurate to count full benefits for all the phosphorus supplied. Rather, the phosphorus in excess of crop needs is unused and is carried over for possible use in later years. Thus, the phosphorus in excess of crop needs should not be counted as a benefit to this year's crop, but should be valued as a benefit in later years.

A procedure for calculating the nutrient value of various sludge is shown in the Appendix. This procedure enables the farmer to compute the amount of nitrogen, phosphorus and heavy metals associated with alternative

Table 8. Potential Value of Nutrients in One Ton of Dry Sewage Sludge With Alternative Levels of Nutrients*

	Nutrient Level					
	Low		Average		High	
Nutrient	Percent of Dry Sludge	Value ($/ton)	Percent of Dry Sludge	Value ($/ton)	Percent of Dry Sludge	Value ($/ton)
Nitrogen†	1.5%	$ 8.10	3.3%	$17.82	5.0%	$27.00
Phosphate (P_2O_5)	1.1	4.40	5.3	21.20	9.2%	36.80
Potash (K_2O)	0.12	0.24	0.4	0.80	2.4%	4.80
TOTAL		$12.74		$39.92		$68.60

*Nutrient price assumptions: Nitrogen, $0.27 per pound; P_2O_5, $0.20 per pound; K_2O, $0.10 per pound.

†Nitrogen is assumed to be composed of 67 percent organic nitrogen and 33 percent ammonia nitrogen. This composition varies greatly among waste treatment plants. All the ammonia nitrogen is available to the crop while only about 30 percent of the organic nitrogen is available in the year when applied. This also assumes that there is no volatization loss of ammonia.

sludge application rates. The value of sludge can be estimated by multiplying the pounds of nitrogen and phosphorus supplied by the sludge times the market price for nitrogen and phosphorus. (The potassium content is normally so low that it can be ignored.)

Land Spreading Versus Other Disposal Alternatives

Compared to conventional means of sludge disposal, land spreading may be the least cost option. Landfilling sewage sludge costs about 50 percent more than does land spreading and groundwater pollution may occur with this method. Incineration is nearly twice as expensive as land spreading but air pollution problems may be present. Lagooning is often practiced but is only a temporary alternative.

Size of community or amount of sludge is an important determinant of disposal costs. A 1980 survey of Ohio's land spreading communities showed substantial economies of size with disposal costs averaging about $45 (1980 $) per dry ton for the mean plant capacity (which is slightly more than six million gallons per day sewage flow). For a plant with half that capacity, disposal costs averaged $60 per dry ton.

With a $45 per dry ton disposal cost and a $40 per dry ton average nutrient value, the community at large (farmers and urban population) has average net disposal costs of only $5 per dry ton. Viewing land spreading from the perspective of the community at large implies that communities cannot afford to use landfilling or incineration. However, negative public reaction either to land spreading or to sludge containing high concentrations of heavy metals often forces cities to resort to higher cost disposal options.

Several land spreading methods are available including: (1) spreading liquid (2 to 8 percent solids) sludge with tank trucks or a tank wagon pulled by a tractor; (2) dewatering liquid sludge to 20 to 30 percent solids and spreading with a truck spreader; and (3) using a semi-trailer "nurse truck" to transport liquid or dewatered sludge to spreading vehicles. Temporary storage for sludge for periods when land is not accessible is essential in a complete system.

The choice of spreading technology is largely dependent on the amount of sludge to be hauled and the distance it must be hauled. In cities with large amounts of sludge and distant land spreading sites, dewatering the sludge to 20-30 percent solids results in the lowest cost alternative. For most small and moderate sized communities with nearby land spreading sites, spreading liquid sludge is preferred. "Nurse" trucks offer economic advantages to those communities transporting sludge more than 5 to 10 miles. Temporary storage is recommended for those periods when land spreading is not possible.

Finally, while land spreading might have economic advantages over traditional means of sludge disposal, communities might do well to consider still another option: composting. Municipalities in different parts of the country have found that the capital and operating costs associated with compost production are more than compensated for by the ability to sell that product to landscapers and other consumers at a relatively high price. So far, Columbus is the only Ohio city that manufactures compost. However, officials of other cities as well as OARDC scientists are investigating the viabililty of this sludge disposal method.

REGULATORY AND CONTRACTUAL CONSIDERATIONS

Requirements and Responsibilities

The land application of sewage sludge for agricultural purposes shall be performed in compliance with the detail plans approved by Ohio Environmental Protection Agency (EPA) according to Sections 6111.45 and 6111.46 of the Ohio Revised Code and Rule 3745-31-02(c) of the Ohio Administrative Code.

A detail plan must be submitted for every land application program using the latest issue of Bulletin 598, Ohio Guide for Land Application of Sewage Sludge, the Ohio EPA Land Application of Sludge Manual and Rule 3745-31-02(c) of Ohio Administrative Code as the appropriate guidelines.

It is important for landowners to understand that an approved plan for sludge application does not remove their responsibility for water pollution or health hazards that may result from the application of sludge on their land. Plan approval means that, in the judgment of Ohio EPA, the proposed system should function satisfactorily. However, it is possible that unforeseen problems might arise. In such situations, the Ohio EPA would give the landowner a reasonable period of time to rectify the problem. Of course, the landowner should also reserve the option to discontinue sludge application on farmland in the event of such unforeseen problems.

Some county health departments have adopted regulations that control the application of sludge to farm land. The regulations license the haulers and control where the sludge is to be applied. Local health departments usually work with Ohio EPA when approving sites. Contact with the local health department before applying sludge is recommended.

Contracts

Beyond the control exercised by and through the regulatory agencies, a written contract between the landowner and sewage sludge applicator is highly advisable. In some instances the applicator will be the municipality and in other cases it will be a private applicator who is transporting and spreading for the municipality. The importance of such a contract is especially critical when a private applicator obtains sludge from more than one source.

The principal advantage of a written contract is to insure that both parties understand the agreement prior to applying the sludge. Often oral contracts are entered with the best of intentions, but the landowner and applicator have differing notions of the rights and obligations of each party. In some cases, the contract may serve as evidence in disputes concerning the performance of either the applicator or the landowner.

Suggested provisions of contracts between the applicator and landowner include:

1. Identification of the landowner and governmental unit or applicator spreading the sludge.

2. Location of land where spreading is to occur and boundaries of application.

3. Entrance and exit points to land that spreading trucks are to use.

4. Specification of the range of sludge quality permitted on the land. Parameters identified might include percent of total solids and levels of zinc, copper, nickel, lead and cadmium.

5. A periodic analysis of the sludge that should provide the farmer with levels of nutrients (nitrogen, phosphorus, potassium and trace elements) available in the sludge. The contract would specify who is to pay for the analysis and frequency of analysis.

6. Agreement on disposal scheduling during the cropping season. Application rates and acceptable periods of application should be identified for growing crops.

7. Agreements on disposal or storage during periods when the soil is wet.

8. Agreements on the application rate. This rate might vary throughout the year depending upon the contents of the sludge and when and where the application is occurring.

9. Restrictions on usage of land for root crops, fresh vegetables or livestock production.

10. Conditions under which either party may escape from provisions of the contract.

APPENDIX

Calculation of Sludge Application Rates

If sludge samples are analyzed by the Research-Extension Analytical Laboratory (REAL) at the Ohio Agricultural Research and Development Center, Wooster, Ohio, the Sewage Sludge Analysis Report will include the following data given below.

Information needed: (Record on accompanying WORK SHEET)

Sludge Analysis--Solids (%), total Kjeldahl nitrogen, ammonium nitrogen, total P, total K, and total copper, nickel, zinc, cadium, and lead.

Soil Analysis--pH, lime test index, cation exchange capacity (CEC), available P and available K.

Crop Information--previous crop, future crop, yield goal (corn, soybeans, wheat and small grains in bushels per acre; forages in tons per acre), P_2O_5 and K_2O required for specific yield goal and soil test results in pounds per acre. (Use the "Agronomy Guide," Ohio Cooperative Extension Service Bulletin 472.)

Calculations

<u>Step 1</u>--Convert all sludge analysis data from ppm (dry weight) or mg per kg (dry weight) to lbs per dry ton.

ppm or mg per kg x 0.002 = lbs. per dry ton

<u>Step 2</u>--Determine the N, P and K needs of the crop to be grown. From the "Agronomy Guide" tables, record the fertilizer needs for N, P and K based on yield goals, previous crop and soil test data on the WORK SHEET.

(a) Record lbs of N needed per acre

(b) Convert lbs of P_2O_5 to lbs of P needed lbs of P_2O_5 x 0.44 = lbs/acre of P needed

(c) Convert lbs of K_2O to lbs of K needed lbs of K_2O x 0.83 = lbs/acre of K needed

<u>Step 3</u>--Calculate sludge available N in lbs/dry ton.

(a) Organic N = Total Kjeldahl N (lbs/ton) - ammonia N (lbs/ton)

(b) Available N = ammonia N (lbs/ton) + 0.3 x organic N (lbs per ton) less losses

<u>Step 4</u>--Calculate sludge application rates to supply plant N or P needs.

(a) For N needs of crop tons of sludge needed per acre = lbs of N needed per acre (Step 2a) divided by available N (lbs per ton of sludge) from Step 3b

(b) For P needs of crop, tons of sludge needed per acre = lbs of P needed per acre (Step 2b) divided by P (lbs per ton of sludge) from Step 1

<u>Step 5</u>--Calculate the number of gallons of <u>liquid</u> sludge needed to supply N or P.

(a) Use Figure 5 to find gallons of sludge per dry ton at _______% solids.

(b) Total gallons of sludge needed = gallons sludge per day ton (Step 5a) x tons dry sludge needed to supply N or P (Step 4a or 4b).

(c) Record gallons of sludge applied per acre by application vehicle. (Data from treatment plant or sludge hauler.)

$$\frac{\text{tons of sludge}}{\text{acre}} = \frac{\text{gal. of sludge/acre (Step 5c)}}{\text{gal. of sludge/dry ton (Step 5a)}}$$

(d) Find tons of dry sludge applied per acre.

(e) Determine number of applications (passes) needed by dividing 4(a) or 4(b) by 5(d).

<u>Step 6</u>--Calculate the amount of each metal added (Cu, Ni, Zn, Cd, Pb) at chosen rate of application. Record on WORK SHEET.

(a) Metal added per acre = pounds metal per ton (Step 1) x actual sludge application rate (tons per acre) from Step 5d.

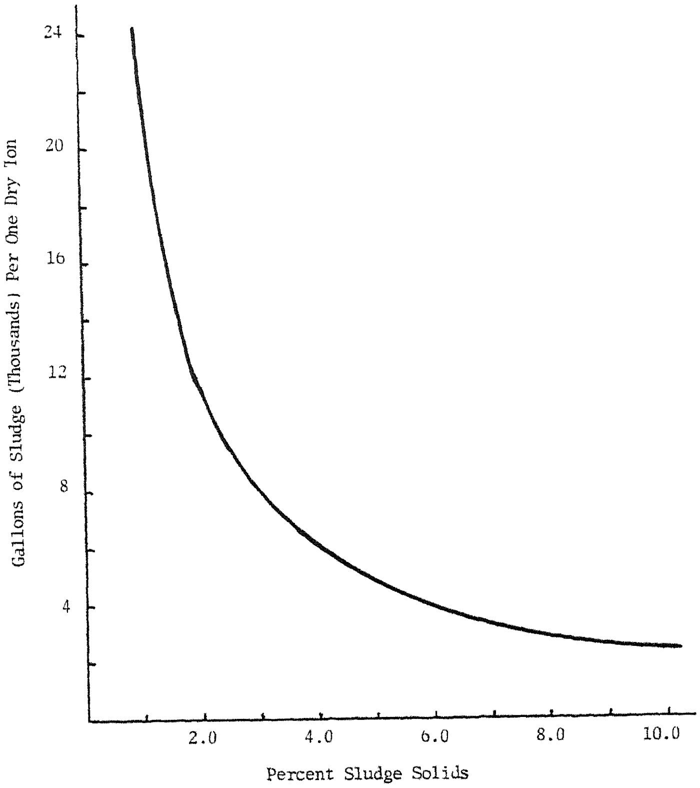
(b) Actual Cd loading rate

If greater than 2 lbs per acre, reject sludge for land application, or reduce application rate.

(c) For specific soil, calculate the number of dry tons of sludge (at the analysis given) that can be safely applied without plant toxicity.

Use Table 7 to find quantity of maximum loading of each metal for soil. Obtain CEC from soil test analysis.

Maximum amount of sludge in tons per acre for each metal equals value from Table 7 divided by lbs of metal per ton from Step 1 for each metal.



WORK SHEET

Step 1: Sludge Analysis[1]

	mg/kg x .002 = lbs per dry ton		
Total N	______	x .002	____________
NH_4-N	______	x .002	____________
Total P	______	x .002	____________
Total K	______	x .002	____________
Copper (Cu)	______	x .002	____________
Nickel (Ni)	______	x .002	____________
Zinc (Zn)	______	x .002	____________
Cadmium (Cd)	______	x .002	____________
Lead (Pb)	______	x .002	____________

[1]All analytical values should be expressed on a dry solid basis as mg/kg or ppm.

Soil Test Analysis

pH ______
Lime test index (LTI) ________
CEC ____________ meq per 100g
Available P ____________ lbs per acre
Available K ____________ lbs per acre

Crop Information (Use Agronomy Guide, Bulletin 472)

Step 2: Previous crop ____
Future crop ____ yield goal ________________
Fertilizer required: (a)________ lbs N per acre
________ lbs P_2O_5 per acre (x 0.44) = (b) ________ lbs P per acre
________ lbs K_2O per acre (x 0.83) = (c) ________ lbs K per acre

Step 3: Sludge Available N

Step 3a Organic N = ________lbs per dry ton
Step 3b Availalbe N = ________ lbs per dry ton

Step 4: Sludge Application Rates

Step 4a Tons of sludge per acre ________________________ For N needs of crop
Step 4b Tons of sludge per acre ________________________ For P needs of crop

Step 5: Gallons of liquid sludge needed to supply N or P

Percent Sludge solids _________%

Step 5a ________ gal. of sludge per dry ton
Step 5b ________ gal. of sludge per acre for N or P needs
Step 5c ________ application rate (gal. per acre) in one pass
Step 5d ________ tons dry sludge applied per acre in one pass
Step 5e ________ number of passes needed to apply N or P needs

Step 6: Evaluation of sludge safety with respect to metals

a) Sludge application rate ________ tons per acre[2]
Metals added with sludge:
Copper (Cu) __________ lbs. per acre
Nickel (Ni) __________ lbs. per acre
Zinc (Zn) __________ lbs. per acre
Cadmium (Cd) __________ lbs. per acre
Lead (Pb) __________ lbs. per acre

[2]This could be the rates planned to provide the N needs of the crop, P needs of crop or an actual application rate.

b) Actual Cadmium loading rate __________ lbs. per acre per year
If greater than 2 lbs. per acre per year do not apply sludge on land or reduce rate of application to apply less than 2 lbs. Cd per acre per year.

c) Maximum amount of sludge which can be safely applied based on sludge content of each metal.

Copper (Cu) __________ tons per acre
Nickel (Ni) __________ tons per acre
Zinc (Zn) __________ tons per acre
Cadmium (Cd) __________ tons per acre
Lead (Pb) __________ tons per acre

If the sludge application rate exceeds any of the rates in 6(c), reduce loading rates accordingly. Otherwise keep records of quantities of each metal applied each year. Stop sludge application when loading reaches maximimum given in Table 7. Also account for any previous heavy metal accumulation according to the section entitled "Background - Heavy Metals."